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DETERMINATION OF THE BEST WING LOADING FOR SINGLE-SEATER PURSUIT AIRPLANES

(AIRPLANE SECTION, S. & A. BRANCH)

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DETERMINATION OF THE BEST WING LOADING FOR SINGLE-SEATER PURSUIT AIRPLANES.

OBJECT.

The object of the investigation covered by this report was to determine the effect of changes in wing loading and aspect ratio on the performance and weight of single-seater pursuit airplanes. This information was obtained by making six preliminary wing designs for an airplane of this type using two aspect ratios and three wing loadings. It was intended to use three aspect ratios, but that was found unnecessary. Only rough preliminary designs were made, as it was believed that the results were as good for comparative purposes as if more refined designs had been used. The type of structure and the approximations used are given below.

CONCLUSIONS.

The lighter the wing loading the better will be the performance of a single-seater pursuit airplane in most particulars. The greatest advantages are in ceiling and rate of climb, while there is a slight advantage in high speed when near the ceiling. In the cases considered, the time of climb to 15,000 feet was 35 per cent longer for the most highly loaded airplane than for the most lightly loaded one; and there was a difference of 2,600 feet between the service ceilings of the same two airplanes.

Higher speed near the ground is obtained by using a heavy loading, but this advantage disappears at altitude. At the ground the maximum difference in speed is 7.5 miles per hour. At 15,000 feet it is only 3.5 miles per hour, and above 20,000 feet the lightly loaded airplane has the higher speed. Thus, at the altitudes at which the pursuit airplane is expected to work, the lightly loaded airplane can climb higher and more quickly and can go as fast as the heavily loaded airplane.

The only effect of a change in aspect ratio on the performance is through the change in efficiency of the wings. As this effect is small in the range investigated, no allowance was made for it. The lower the aspect ratio, however, the lower will be the weight of the wing structure, as the spars will be both lighter per foot of length and shorter.

The change in performance due to a variation of 12 per cent in the weight of the wing structure is negligible.

The dead weight per square foot of the wings increases with an increase of either aspect ratio or wing loading. The maximum difference between the designs made for this report was only about 12 per cent of the total weight of the wings.

The lightest practicable wing loading should be used for single-seater pursuit airplanes. Just what this loading should be in any particular case depends on considerations of vision, maneuverability, storage, etc., which can not be compared quantitatively with performance. Therefore the exact value used must be chosen by the judgment of the designer.

METHOD OF DESIGN.

In order to reduce the labor of computation the simplest type of construction was assumed and certain assumptions were made to simplify the work still further. As a result the spar and strut sizes selected would not be the correct sizes to use in an actual design, but as the same assumptions and approximations were used for all the designs valid comparisons may be made from the data obtained. The designs were carried out following the methods outlined in "Stress Analysis and Design of Airplanes," except that drag forces were neglected and the design loads on the front and rear trusses were assumed to be 6 *W* and 4 *W*, respectively, where *W* was the weight of the airplane minus wings. These values are slightly higher than would be obtained from the assumed spar locations and load factors and the center of pressure travel of the aerofoil used, but were used to simplify computations.

The following data were assumed in all designs:

Aerofoil section........................R. A. F..	15
Location of the front spar in per cent of chord.....	13
Location of the rear spar in per cent of chord.......	65
Stagger..	None.
Efficiency of lower wing................per cent..	90
Gap-chord ratio..................................	1.0

Spars hinged at center section.
Wing tips square.
Both wings of same span and chord.
Front and rear struts alike.
Upper and lower spars alike.

After designing the spars and struts, their weight per square foot of wing area was computed. The remainder of the wing structure, including fabric, drag trussing, etc., was assumed to have the same weight per square foot of wing area for all designs. Assuming the lightest wing to weigh 1 pound per square foot, the weights of the other wings were easily computed.

The wing loading was then revised and the power loading computed, using 328 horsepower for each design. This is the normal horsepower of the Packard-1237 engine, which is a typical engine for the type of airplane considered. For computing the fineness, an equivalent flat plate area of 5 square feet was assumed to represent the structural resistance and the fineness obtained from the chart, figure 1.

DESCRIPTION OF CHART.

In a report entitled "Airplane Performance and Design Chart"[1] it was pointed out that "fineness" depended on the parasite resistance and on the loading per square foot of wing surface. Recent developments have shown that "fineness" can be expressed as a function of equivalent flat plate area and of wing area and section. Figure 1 gives this function graphically for R. A. F. 15 wing section. It was obtained in the following manner:

Given

$$W=\delta K_y F V^2 \qquad (1)$$

and

$$\eta H.P.=(\delta K_x F V^3+0.64\,\delta A_e V^3)/550 \qquad (2)$$

where F=wing area in square feet.

η=propeller efficiency.

A_e=equivalent flat plate area of parasite resistance.

δ=density=0.00237.

V=velocity in ft./sec.

K_x and K_y in absolute units.

By the method of least squares, K_x can be expressed as a function of K_y

$$K_x=A+B\,K_y^2 \qquad (3)$$

where A=0.007 and B=0.146 for R. A. F. 15.

Simultaneous solution of equations (1), (2), and (3) yields the following:

$$550\,\eta\,H.P.=\frac{\delta A W}{\phi}V^3+\frac{B\phi W}{\delta V}+0.64\delta A_e\,V^3 \qquad (4)$$

where $\phi=\frac{W}{F}$=wing loading.

Substituting various values of $H.P.$, W, ϕ and A_e, this equation was solved for V and "fineness" then found from the "Airplane Performance and Design Chart." Figure 1 is thus obtained, and it will be noted that the relation can be expressed by one curve, "fineness"$=f(A_e/F)$. Thus it is seen that the smaller the parasite area for a given wing area, the greater the "fineness" and hence performance. An extended discussion of this subject will appear later in a special report on "fineness."

COMPUTATION OF PERFORMANCE DATA.

Knowing the wing loading, power loading, and fineness, the performances were obtained from the Airplane Performance Chart in Air Service Information Circular, Vol. II, No. 183.

Table I gives the essential data on the six designs on which this report is based, in regards to both structural weight and performance.

TABLE I.—*Weight and performance data on assumed designs.*

ϕ	Case I.	Case II.	Case III.	Case IV.	Case V.	Case VI.
Aspect ratio	5.5	5.5	5.5	5.0	5.0	5.0
Wing loading (approx.), lbs. per sq. ft	7.12	8.46	9.98	7.04	8.62	9.98
Chord, inches	70	63.5	58	74	66	61
Wing area, sq. ft	361	295	245	365	289	245.5
Spar area (one wing), sq. in	10.03	9.96	9.97	8.68	8.76	8.57
Spar weight, lbs. per ft	1.881	1.868	1.869	1.628	1.643	1.607
Spar weight, lbs. per sq. ft. of wing	0.322	0.352	0.386	0.264	0.299	0.316
Area of 1 strut, sq. in	5.53	5.04	4.56	5.72	5.09	4.71
Length of strut, inches	66	60	55	70	62	57.5
Weight of 4 struts, lbs	22.8	18.9	15.68	25.0	19.7	16.95
Weight of struts, lbs. per sq. ft. of wing	0.061	0.064	0.064	0.068	0.068	0.069
Weight of ribs, etc., lbs. per sq. ft	0.668	0.668	0.668	0.668	0.668	0.668
Weight of wings, lbs. per sq. ft	1.051	1.084	1.118	1.000	1.035	1.053
Weight of wings, lbs	379	320	274	365	299	259
Total weight, lbs	2,579	2,520	2,474	2,565	2,499	2,459
Wing loading, lbs. per sq. ft	7.14	8.54	10.10	7.03	8.65	10.01
Power loading, lbs. per h. p	7.86	7.68	7.54	7.82	7.62	7.50
Fineness	122.8	117.5	112.5	122.8	117.0	112.5
y[1]	1.66	1.89	2.11	1.66	1.90	2.10
Velocity at ground, m. p. h	146.3	149.0	153.0	145.5	149.5	153.0
Velocity at 10,000 ft., m. p. h	145.0	146.6	148.5	144.5	146.9	148.4
Velocity at 15,000 ft., m. p. h	138.6	139.7	141.3	138.1	140.1	141.0
Velocity at service ceiling, m. p. h	109.3	113.5	119.0	108.9	114.0	118.8
Climb at ground, ft. per min	1,785	1,595	1,465	1,770	1,585	1,480
Time to 10,000 ft., min	6.6—	7.5	8.5—	6.6	7.5	8.4
Time to 15,000 ft., min	12.2	14.1	16.5	12.3	14.1	16.2
Time to service ceiling, min	41.0	41.3	41.0	41.5	41.2	41.0
Service ceiling, ft	24,025	22,900	21,400	24,050	22,800	21,000
Velocity at 20,000 ft. (interpolated from curves), m. p. h	126.8	126.7	126.6	126.5	127.3	126.6—

[1] y is the ordinate on the performance chart for the given power loading and fineness.

Several interesting facts were brought out in the computations for the six designs in addition to the main conclusions given above.

1. For a given aspect ratio and gap-chord ratio and varying wing loadings, the net area of spars tends to be constant. The areas of the spars of the designs in question were not exactly constant, but the differences were apparently due mainly if not entirely to the variations in the efficiency with which the material was used. With the higher wing loadings the moments are smaller, but this is counteracted by the decrease in the depth of the spars, so the same sectional area must be used.

2. The direct stresses in the lift trusses do not vary with either aspect ratio or wing loading, but only with the proportions of the truss. A change in the gap-chord ratio or the ratio of cantilever length to length of bay will cause a change in the direct stresses.

3. With a given gap-chord ratio the size of the struts varies with the chord, but for a given aspect ratio the weight of struts per square foot of wing is constant.

4. In figure 1 the fineness is independent of the aspect ratio. Therefore, the effect on performance of a change of aspect ratio is only the negligible changes due to the variation in the structural weight and efficiency of the wings.

[1] Air Service Information Circular, Vol. II, No. 183. McCook Field Report No. 1380.

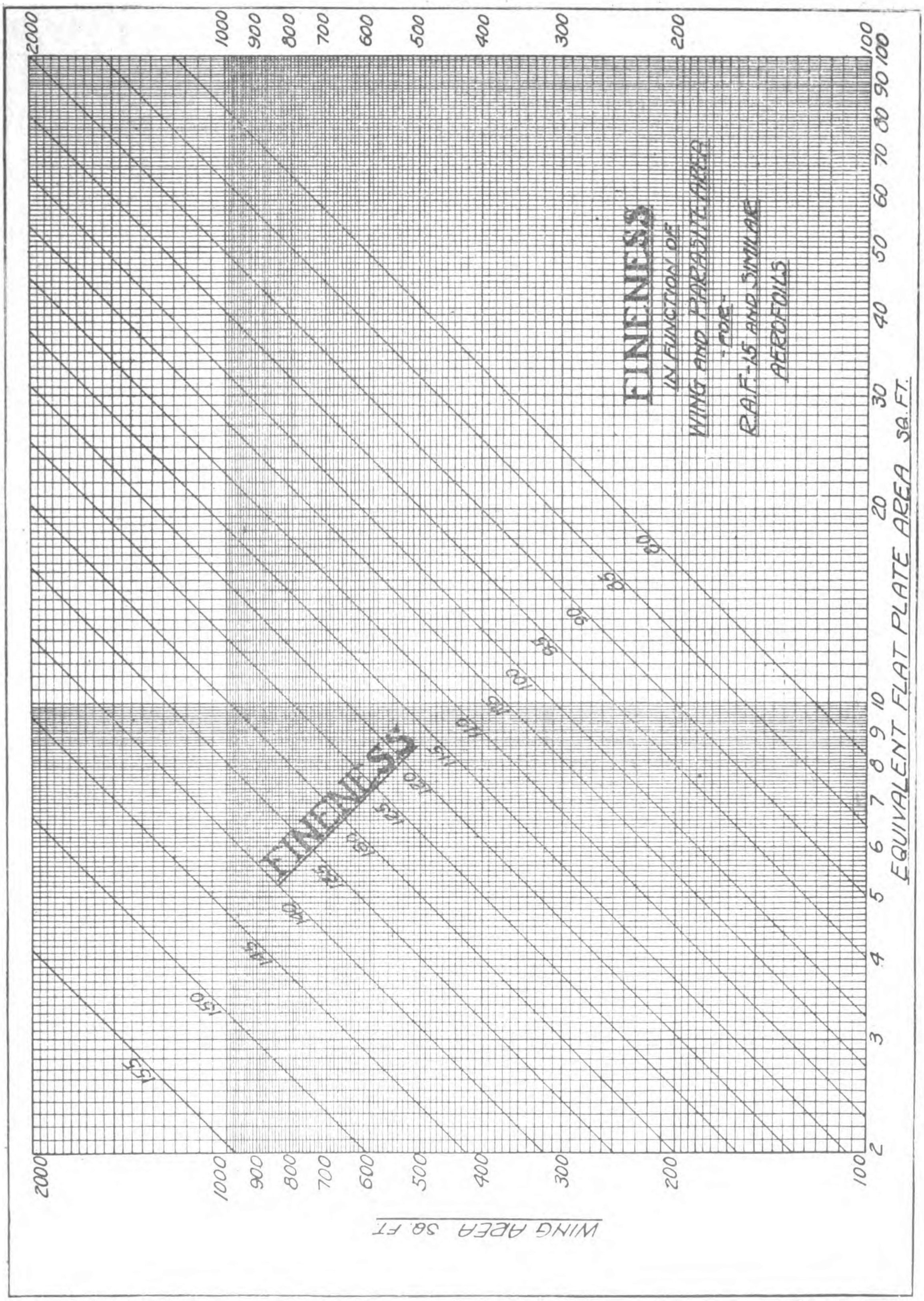
FINENESS
IN FUNCTION OF
WING AND PARASITE AREA
-FOR-
R.A.F.-15 AND SIMILAR
AEROFOILS
EQUIVALENT FLAT PLATE AREA SQ. FT.
WING AREA SQ. FT.
FINENESS

FIG. 1.